CLAIMS

1. An objective lens used for an optical pickup device,

wherein the optical pickup device comprises: a light source; and a converging optical system including the objective lens for converging a light beam emitted from the light source to an information recording surface of an optical information recording medium, and

the optical pickup device is capable of recording and/or reproducing information by converging the light beam emitted from the light source to the information recording surface of the optical information recording medium with the converging optical system, and

wherein the objective lens is a plastic single lens and satisfies following formulas:

$$NA \geq 0.8 \quad (1)$$

$$1.0 > f > 0.2 \quad (2)$$

where NA is an image-side numerical aperture of the objective lens, which is required for recording and/or reproducing information to the optical information recording medium and f (mm) is a focal length of the objective lens.

2. The objective lens for the optical pickup device of claim 1, wherein in case that $W(\lambda_0, T_0)$ is an RMS

value of residual aberration of the objective lens when light having a wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C and $W(\lambda_0, T_1)$ is an RMS value of residual aberration of the objective lens when light having the wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at the environmental temperature which is a second ambient temperature T_1 = 55 °C, ΔW defined by

$$\Delta W = |W(\lambda_0, T_1) - W(\lambda_0, T_0)| \qquad (3)$$

satisfies a following formula:

$$\Delta W < 0.035\ \lambda rms \qquad (4)$$

3. The objective lens for the optical pickup device of claim 1 or 2, wherein the design wavelength λ_0 of the optical objective lens is not more than 500 nm, and in case that $fB(\lambda_0, T_0)$ is a back focal length of the objective lens when light having a wavelength of λ_0 (nm) is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C and $fB(\lambda_1, T_0)$ is a back focal length of the objective lens when light having a wavelength of λ_1 (nm) which is 5 nm longer than the wavelength of λ_0 incident to the objective lens at the environmental temperature which is the first ambient temperature T_0 = 25 °C, ΔfB defined by

$$\Delta fB = |fB(\lambda_1, T_0) - fB(\lambda_0, T_0)| \quad (5)$$

satisfies a following formula:

$$\Delta fB < 0.001 \text{ mm} \quad (6)$$

4. The objective lens for the optical pickup device of any one of claims 1 to 3, wherein the objective lens is an objective lens of a finite conjugate type for converging a diverging light beam emitted from the light source to the information recording surface of the optical information recording medium and satisfies a following formula:

$$0.8 > f > 0.2 \quad (6A)$$

5. The objective lens for the optical pickup device of claim 4, wherein m satisfies a following formula when m is an image formation magnification of the objective lens:

$$0.2 > |m| > 0.02 \quad (6B)$$

6. An objective lens used for an optical pickup device,

wherein the optical pickup device comprises a light source; and a converging optical system including an objective lens for converging a light beam emitted from the light source to an information recording surface of an optical information recording medium, and

the optical pickup device is capable of recording and/or reproducing information by converging the light beam emitted from the light source to the information recording surface of the optical information recording medium with the converging optical system,

wherein the objective lens is a plastic single lens that comprises a ring-shaped phase structure on at least one optical surface, the ring-shaped phase structure comprising a plurality of ring surfaces and formed so that adjacent ring surfaces generate a predetermined optical path difference for incident light, and satisfies following formulas:

$$NA \geq 0.8 \qquad (7)$$

$$1.3 > f > 0.2 \qquad (8)$$

where NA is an image-side numerical aperture of the objective lens, which is required for recording and/or reproducing information for the optical information recording medium and f (mm) is a focal length of the objective lens.

7. The objective lens for the optical pickup device of claim 6, wherein the ring-shaped phase structure is a diffraction structure having a function for diffracting predetermined incident light and the objective lens forms a converging wave front which is converged on the information recording surface owing to an effect

obtained by combining a diffraction effect and a refraction effect.

8. The objective lens for the optical pickup device of claim 7, wherein the objective lens has a spherical aberration characteristic that spherical aberration changes in an undercorrected direction when a wavelength of the incident light changes to a longer wavelength.

9. The objective lens for the optical pickup device of claim 7 or 8, wherein when an optical path difference added to a wave front transmitted through the diffraction structure is denoted by an optical path difference function Φ_b defined by

$$\Phi_b = b_2 \cdot h^2 + b_4 \cdot h^4 + b_6 \cdot h^6 + \ldots$$

(wherein b_2, b_4, b_6... are 2nd-order, 4th-order, 6th-order... optical path difference function coefficients, respectively), a following formula is satisfied:

$$-70 < (b_4 \cdot h_{MAX}{}^4)/(f \cdot \lambda_0 \cdot 10^{-6} \cdot (NA \cdot (1-m))^4) < -20 \qquad (8A)$$

wherein λ_0 (nm) is a design wavelength of the objective lens, h_{MAX} is an effective diameter maximum height (mm) of the optical surface on which the diffraction structure is formed and m is an image formation magnification of the objective lens.

10. The objective lens for the optical pickup device of claim 6, wherein the ring-shaped phase structure generates the predetermined optical path difference for the incident light by forming the adjacent ring surfaces so as to be displaced in an optical axis direction each other, and the objective lens forms a converging wave front which is converged on the information recording surface owing to a refraction effect.

11. The objective lens for the optical pickup device of claim 10, wherein when a ring surface including an optical axis is called a central ring surface, a ring surface adjacent to an outside of the central ring surface is formed to be displaced in the optical axis direction so as to have a shorter optical path length than the central ring surface, a ring surface at a maximum effective diameter position is formed to be displaced in the optical axis direction so as to have a longer optical path length than an ring surface adjacent to an inside thereof, and a ring surface at a position of 75% of a maximum effective diameter is formed to be displaced so as to have a shorter optical path length than a ring surface adjacent to an inside thereof and a ring surface adjacent to an outside thereof.

12. The objective lens for the optical pickup

device of claim 10 or 11, wherein a total of the ring surfaces is from 3 to 20.

13. The objective lens for the optical pickup device of any one of claims 10 to 12, wherein when Δ_j (μm) is a step amount of an arbitrary step of steps in the optical axis direction at a boundary of mutually adjacent ring surfaces in a ring-shaped phase structure formed in a region from a height of 75% to a height of 100% of an effective diameter maximum height of the optical surface on which the ring-shaped phase structure is formed and n is a refractive index of the objective lens at a design wavelength of λ_0 (nm), m_j represented by

$$m_j = INT(X) \qquad (8B)$$

(wherein $X = \Delta_j \cdot (n-1)/(\lambda_0 \cdot 10^{-3})$ and INT(X) is an integer obtained by half adjust of X) is an integer not less than 2.

14. The objective lens for the optical pickup device of any one of claims 6 to 13, wherein in case that $W(\lambda_0, T_0)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C, $W(\lambda_1, T_0)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_1 (nm) which is 5 nm longer

than the wavelength of λ_0 is incident to the objective lens at the environmental temperature which is the first ambient temperature $T_0 = 25$ °C and $W(\lambda_2, T_1)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_2 (nm) is incident to the objective lens at the environmental temperature which is a second ambient temperature $T_1 = 55$ °C, $\Delta W1$ and $\Delta W2$ defined by

$$\Delta W1 = |W(\lambda_2, T_1) - W(\lambda_0, T_0)| \quad (9)$$

$$\Delta W2 = |W(\lambda_1, T_0) - W(\lambda_0, T_0)| \quad (10)$$

satisfy following formulas:

$$\Delta W1 < 0.035\ \lambda rms \quad (11)$$

$$\Delta W2 < 0.035\ \lambda rms \quad (12)$$

wherein

when $\lambda_0 < 600$ nm, $\lambda_2 = \lambda_0 + 1.5$ (nm) and

when $\lambda_0 \geq 600$ nm, $\lambda_2 = \lambda_0 + 6$ (nm).

15. The objective lens for the optical pickup device of claim 14, wherein the objective lens satisfies a following formula:

$$\sqrt{((\Delta W1)^2 + (\Delta W2)^2)} < 0.05\ \lambda rms \quad (13)$$

16. The objective lens for the optical pickup device of any one of claims 6 to 15, wherein the objective lens is an objective lens of a finite conjugate type for converging a diverging light beam emitted from the light source on the information recording surface and satisfies a

following formula:

$$1.1 > f > 0.2 \qquad (13A)$$

17. The objective lens for the optical pickup device of claim 16, satisfying a following formula when m is an image formation magnification of the objective lens:

$$0.2 > |m| > 0.02 \qquad (13B)$$

18. The objective lens for the optical pickup device of any one of claims 1 to 17, wherein the objective lens satisfies a following formula:

$$0.8 < d/f < 1.8 \qquad (14)$$

where d (mm) is a lens thickness in an optical axis of the objective lens and f (mm) is the focal length.

19. The objective lens for the optical pickup device of any one of claims 1 to 18, wherein the design wavelength of λ_0 (nm) of the objective lens satisfies a following formula:

$$500 \geq \lambda_0 \geq 350 \qquad (15)$$

20. The objective lens for the optical pickup device of any one of claims 1 to 19, wherein the objective lens satisfies a following formula:

$$0.40 \leq (X1 - X2) \cdot (N - 1)/(NA \cdot f \cdot \sqrt{(1 + |m|)}) \leq 0.63 \qquad (16)$$

where

X1: a distance (mm) in an optical axis direction between a plane that is perpendicular to an optical axis and tangent to a top of an optical surface on a light source side and an optical surface on the light source side in a most peripheral portion of an effective diameter (position of the NA on a surface on the light source side to which a marginal light beam is incident), wherein X1 is plus in a case of measuring X1 in a direction of the optical information recording medium with reference to the tangent plane, and minus in a case of measuring X1 in a direction of the light source,

X2: a distance (mm) in an optical axis direction between a plane that is perpendicular to an optical axis and tangent to a top of an optical surface on an optical information recording medium side and an optical surface on the optical information recording medium side in a most peripheral portion of an effective diameter (position of the NA on a surface on the optical information recording medium side to which a marginal light beam is incident), wherein X2 is plus in a case of measuring X2 in a direction of the optical information recording medium with reference to the tangent plane and minus ina case of measuring X2 in a direction of the light source,

N: a refractive index of the objective lens at the design wavelength of λ_0,

f: the focal length (mm) of the objective lens, and

m: an image formation magnification of the objective lens.

21. An optical pickup device comprising: a light source; and a converging optical system including an objective lens for converging a light beam emitted from the light source to an information recording surface of an optical information recording medium, and

wherein the optical pickup device is capable of recording and/or reproducing information by converging the light beam emitted from the light source to the information recording surface of the optical information recording medium with the converging optical system,

wherein the objective lens is a plastic single lens and satisfies following formulas:

$$NA \geq 0.8 \quad (1)$$

$$1.0 > f > 0.2 \quad (2)$$

where NA is an image-side numerical aperture of the objective lens, which is required for recording and/or reproducing information to the optical information recording medium and f (mm) is a focal length of the objective lens.

22. The optical pickup device of claim 21, wherein in case that $W(\lambda_0, T_0)$ is an RMS value of residual

aberration of the objective lens when light having a wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C, and $W(\lambda_0, T_1)$ is an RMS value of residual aberration of the objective lens when light having the wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at the environmental temperature which is a second ambient temperature T_1 = 55 °C, ΔW defined by

$$\Delta W = |W(\lambda_0, T_1) - W(\lambda_0, T_0)| \quad (3)$$

satisfies a following formula:

$$\Delta W < 0.035\ \lambda rms \quad (4)$$

23. The optical pickup device of claim 21 or 22, wherein the design wavelength λ_0 of the optical objective lens is not more than 500 nm, and in case that $fB(\lambda_0, T_0)$ is a back focal length of the objective lens when light having a wavelength of λ_0 (nm) is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C and $fB(\lambda_1, T_0)$ is a back focal length of the objective lens when light having a wavelength of λ_1 (nm) which is 5 nm longer than the wavelength of λ_0 is incident to the objective lens at the environmental temperature which is the first ambient temperature T_0 = 25 °C, ΔfB defined by

$$\Delta fB = |fB(\lambda_1, T_0) - fB(\lambda_0, T_0)| \quad (5)$$

satisfies a following formula:

$$\Delta fB < 0.001 \text{ mm} \qquad (6)$$

24. The optical pickup device of any one of claims 21 to 23, wherein the objective lens is an objective lens of a finite conjugate type for converging a diverging light beam emitted from the light source to the information recording surface of the optical information recording medium and satisfies a following formula:

$$0.8 > f > 0.2 \qquad (6A)$$

25. The optical pickup device of claim 24, wherein m satisfies a following formula when m is an image formation magnification of the objective lens:

$$0.2 > |m| > 0.02 \qquad (6B)$$

26. The optical pickup device of claim 24 or 25, wherein the objective lens and the light source are united by an actuator at least to be driven for tracking.

27. An optical pickup device comprising: a light source; and a converging optical system including an objective lens for converging a light beam emitted from the light source to an information recording surface of an optical information recording medium,

wherein the optical pickup device is capable of

recording and/or reproducing information by converging the light beam emitted from the light source to the information recording surface of the optical information recording medium with the converging optical system,

wherein the objective lens is a plastic single lens that comprises a ring-shaped phase structure on at least one optical surface, the ring-shaped phase structure comprising a plurality of ring surfaces and formed so that adjacent ring surfaces generate a predetermined optical path difference for incident light, and satisfies following formulas:

$$NA \geq 0.8 \tag{7}$$

$$1.3 > f > 0.2 \tag{8}$$

where NA is an image-side numerical aperture of the objective lens, which is required for recording and/or reproducing information for the optical information recording medium and f (mm) is a focal length of the objective lens.

28. The optical pickup device of claim 27, wherein the ring-shaped phase structure is a diffraction structure having a function for diffracting predetermined incident light and the objective lens forms a converging wave front which is converged on the information recording surface owing to an effect obtained by combining a diffraction effect and a refraction effect.

29. The optical pickup device of claim 28, wherein the objective lens has a spherical aberration characteristic that spherical aberration changes in an undercorrected direction when a wavelength of the incident light changes to a longer wavelength.

30. The optical pickup device of claim 28 or 29, wherein when an optical path difference added to a wave front transmitted through the diffraction structure is denoted by an optical path difference function Φ_b defined by

$$\Phi_b = b_2 \cdot h^2 + b_4 \cdot h^4 + b_6 \cdot h^6 + \ldots$$

(wherein b_2, b_4, b_6... are 2nd-order, 4th-order, 6th-order... optical path difference function coefficients, respectively), a following formula is satisfied:

$$-70 < (b_4 \cdot h_{MAX}^4)/(f \cdot \lambda_0 \cdot 10^{-6} \cdot (NA \cdot (1-m))^4) < -20 \quad (8A)$$

wherein λ_0 (nm) is a design wavelength of the objective lens, h_{MAX} is an effective diameter maximum height (mm) of the optical surface on which the diffraction structure is formed and m is an image formation magnification of the objective lens.

31. The optical pickup device of claim 27, wherein the ring-shaped phase structure generates the predetermined optical path difference for the incident light by forming

the adjacent ring surfaces so as to be displaced in an optical axis direction each other, and the objective lens forms a converging wave front which is converged on the information recording surface owing to a refraction effect.

32. The objective lens for the optical pickup device of claim 31, wherein when a ring surface including an optical axis is called a central ring surface, a ring surface adjacent to an outside of the central ring surface is formed to be displaced in the optical axis direction so as to have a shorter optical path length than the central ring surface, a ring surface at a maximum effective diameter position is formed to be displaced in the optical axis direction so as to have a longer optical path length than an ring surface adjacent to an inside thereof, and a ring surface at a position of 75% of a maximum effective diameter is formed to be displaced so as to have a shorter optical path length than a ring surface adjacent to an inside thereof and a ring surface adjacent to an outside thereof.

33. The optical pickup device of claim 31 or 32, wherein a total of the ring surfaces is from 3 to 20.

34. The optical pickup device of any one of claims 31 to 33, wherein when Δ_j (μm) is a step amount of an

arbitrary step of steps in the optical axis direction at a boundary of mutually adjacent ring surfaces in a ring-shaped phase structure formed in a region from a height of 75% to a height of 100% of an effective diameter maximum height of the optical surface on which the ring-shaped phase structure is formed and n is a refractive index of the objective lens at a design wavelength of λ_0 (nm), m_j represented by

$$m_j = INT(X) \tag{8B}$$

(wherein $X = \Delta_j \cdot (n-1)/(\lambda_0 \cdot 10^{-3})$ and INT(X) is an integer obtained by half adjust of X) is an integer not less than 2.

35. The optical pickup device of any one of claims 27 to 34, wherein in case that $W(\lambda_0, T_0)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C, $W(\lambda_1, T_0)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_1 (nm) which is 5 nm longer than the wavelength of λ_0 is incident to the objective lens at the environmental temperature which is the first ambient temperature T_0 = 25 °C and $W(\lambda_2, T_1)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_2 (nm) is incident to the objective lens

at the environmental temperature which is a second ambient temperature T_1 = 55 °C, $\Delta W1$ and $\Delta W2$ defined by

$$\Delta W1 = |W(\lambda_2, T_1) - W(\lambda_0, T_0)| \quad (9)$$

$$\Delta W2 = |W(\lambda_1, T_0) - W(\lambda_0, T_0)| \quad (10)$$

satisfy following formulas:

$$\Delta W1 < 0.035 \lambda rms \quad (11)$$

$$\Delta W2 < 0.035 \lambda rms \quad (12)$$

wherein

when λ_0 < 600 nm, $\lambda_2 = \lambda_0$ + 1.5 (nm) and

when $\lambda_0 \geq$ 600 nm, $\lambda_2 = \lambda_0$ + 6 (nm).

36. The optical pickup device of claim 35, wherein the optical pickup device satisfies a following formula:

$$\sqrt{((\Delta W1)^2 + (\Delta W2)^2)} < 0.05 \lambda rms \quad (13)$$

37. The optical pickup device of any one of claims 27 to 36, wherein the objective lens is an objective lens of a finite conjugate type for converging a diverging light beam emitted from the light source on the information recording surface and satisfies a following formula:

$$1.1 > f > 0.2 \quad (13A)$$

38. The optical pickup device of claim 37, the optical pickup device satisfies a following formula:

$$0.2 > |m| > 0.02 \quad (13B)$$

where m is an image formation magnification of the

objective lens.

39. The optical pickup device of claim 37 or 38, wherein the objective lens and the light source are united by an actuator at least to be driven for tracking.

40. The optical pickup device of any one of claims 21 to 39, wherein the optical device satisfies a following formula:

$$0.8 < d/f < 1.8 \qquad (14)$$

where d (mm) is a lens thickness in an optical axis of the objective lens and f (mm) is the focal length.

41. The optical pickup device of any one of claims 21 to 40, wherein the design wavelength of λ_0 (nm) of the objective lens satisfies a following formula:

$$500 \geq \lambda_0 \geq 350 \qquad (15)$$

42. The optical pickup device of any one of claims 21 to 41, wherein the optical pickup device satisfies a following formula:

$$0.40 \leq (X1 - X2)\cdot(N - 1)/(NA\cdot f\cdot\sqrt{(1 + |m|)}) \leq 0.63 \qquad (16)$$

where

X1: a distance (mm) in an optical axis direction between a plane that is perpendicular to an optical axis and tangent

to a top of an optical surface on a light source side and an optical surface on the light source side in a most peripheral portion of an effective diameter (position of the NA on a surface on the light source side to which a marginal light beam is incident), wherein X1 is plus in a case of measuring X1 in a direction of the optical information recording medium with reference to the tangent plane, and minus in a case of measuring X1 in a direction of the light source,

X2: a distance (mm) in an optical axis direction between a plane that is perpendicular to an optical axis and tangent to a top of an optical surface on an optical information recording medium side and an optical surface on the optical information recording medium side in a most peripheral portion of an effective diameter (position of the NA on a surface on the optical information recording medium side to which a marginal light beam is incident), wherein X2 is plus in a case of measuring X2 in a direction of the optical information recording medium with reference to the tangent plane and minus ina case of measuring X2 in a direction of the light source,

N: a refractive index of the objective lens at the design wavelength of λ_0,

f: the focal length (mm) of the objective lens, and

m: an image formation magnification of the objective lens.

43. An optical information recording/reproducing apparatus comprising optical pickup device that comprises: a light source; and a converging optical system including an objective lens for converging a light beam emitted from the light source to an information recording surface of an optical information recording medium,

and is capable of recording and/or reproducing information by converging the light beam emitted from the light source to the information recording surface of the optical information recording medium with the converging optical system,

wherein the objective lens is a plastic single lens and satisfies following formulas:

$$NA \geq 0.8 \quad (1)$$

$$1.0 > f > 0.2 \quad (2)$$

where NA is an image-side numerical aperture of the objective lens, which is required for recording and/or reproducing information to the optical information recording medium and f (mm) is a focal length of the objective lens.

44. The optical information recording/reproducing apparatus of claim 43, wherein in case that $W(\lambda_0, T_0)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at an

environmental temperature which is a first ambient temperature T_0 = 25 °C and $W(\lambda_0, T_1)$ is an RMS value of residual aberration of the objective lens when light having the wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at the environmental temperature which is a second ambient temperature T_1 = 55 °C, ΔW defined by

$$\Delta W = |W(\lambda_0, T_1) - W(\lambda_0, T_0)| \tag{3}$$

satisfies a following formula:

$$\Delta W < 0.035\ \lambda rms \tag{4}$$

45. The optical information recording/reproducing apparatus of claim 43 or 44, wherein the design wavelength λ_0 of the optical objective lens is not more than 500 nm, and in case that $fB(\lambda_0, T_0)$ is a back focal length of the objective lens when light having a wavelength of λ_0 (nm) is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C and $fB(\lambda_1, T_0)$ is a back focal length of the objective lens when light having a wavelength of λ_1 (nm) which is 5 nm longer than the wavelength of λ_0 is incident to the objective lens at the environmental temperature which is the first ambient temperature T_0 = 25 °C, ΔfB defined by

$$\Delta fB = |fB(\lambda_1, T_0) - fB(\lambda_0, T_0)| \tag{5}$$

satisfies a following formula:

$$\Delta fB < 0.001\ mm \tag{6}$$

46. The optical information recording/reproducing apparatus of any one of claims 43 to 45, wherein the objective lens is an objective lens of a finite conjugate type for converging a diverging light beam emitted from the light source to the information recording surface of the optical information recording medium and satisfies a following formula:

$$0.8 > f > 0.2 \tag{6A}$$

47. The optical information recording/reproducing apparatus of claim 46, wherein m satisfies a following formula when m is an image formation magnification of the objective lens:

$$0.2 > |m| > 0.02 \tag{6B}$$

48. The optical information recording/reproducing apparatus of claim 46 or 47, wherein the objective lens and the light source are united by an actuator at least to be driven for tracking.

49. An optical information recording/reproducing apparatus comprising an optical pickup device

wherein the optical pickup device comprises: a light source; and a converging optical system including an objective lens for converging a light beam emitted from the

light source to an information recording surface of an optical information recording medium, and

the optical pickup device is capable of recording and/or reproducing information by converging the light beam emitted from the light source to the information recording surface of the optical information recording medium with the converging optical system,

wherein the objective lens is a plastic single lens that comprises a ring-shaped phase structure on at least one optical surface, the ring-shaped phase structure comprising a plurality of ring surfaces and formed so that adjacent ring surfaces generate a predetermined optical path difference for incident light, and satisfies following formulas:

$$NA \geq 0.8 \qquad (7)$$

$$1.3 > f > 0.2 \qquad (8)$$

where NA is an image-side numerical aperture of the objective lens, which is required for recording and/or reproducing information for the optical information recording medium and f (mm) is a focal length of the objective lens.

50. The optical information recording/reproducing apparatus of claim 49, wherein the ring-shaped phase structure is a diffraction structure having a function for diffracting predetermined incident light and the objective

lens forms a converging wave front which is converged on the information recording surface owing to an effect obtained by combining a diffraction effect and a refraction effect.

51. The optical information recording/reproducing apparatus of claim 50, wherein the objective lens has a spherical aberration characteristic that spherical aberration changes in an undercorrected direction when a wavelength of the incident light changes to a longer wavelength.

52. The optical information recording/reproducing apparatus of claim 50 or 51, wherein when an optical path difference added to a wave front transmitted through the diffraction structure is denoted by an optical path difference function Φ_b defined by

$$\Phi_b = b_2 \cdot h^2 + b_4 \cdot h^4 + b_6 \cdot h^6 + \ldots$$

(wherein b_2, b_4, b_6... are 2nd-order, 4th-order, 6th-order... optical path difference function coefficients, respectively), a following formula is satisfied:

$$-70 < (b_4 \cdot h_{MAX}^4)/(f \cdot \lambda_0 \cdot 10^{-6} \cdot (NA \cdot (1-m))^4) < -20 \qquad (8A)$$

wherein λ_0 (nm) is a design wavelength of the objective lens, h_{MAX} is an effective diameter maximum height (mm) of the optical surface on which the diffraction structure is formed and m is an image formation magnification of the

objective lens.

53. The optical information recording/reproducing apparatus of claim 49, wherein the ring-shaped phase structure generates the predetermined optical path difference for the incident light by forming the adjacent ring surfaces so as to be displaced in an optical axis direction each other, and the objective lens forms a converging wave front which is converged on the information recording surface owing to a refraction effect.

54. The objective lens for the optical pickup device of claim 53, wherein when a ring surface including an optical axis is called a central ring surface, a ring surface adjacent to an outside of the central ring surface is formed to be displaced in the optical axis direction so as to have a shorter optical path length than the central ring surface, a ring surface at a maximum effective diameter position is formed to be displaced in the optical axis direction so as to have a longer optical path length than an ring surface adjacent to an inside thereof, and a ring surface at a position of 75% of a maximum effective diameter is formed to be displaced so as to have a shorter optical path length than a ring surface adjacent to an inside thereof and a ring surface adjacent to an outside thereof.

55. The optical information recording/reproducing apparatus of claim 53 or 54, wherein a total of the ring surfaces is from 3 to 20.

56. The optical information recording/reproducing apparatus of any one of claims 53 to 55, wherein when Δ_j (μm) is a step amount of an arbitrary step of steps in the optical axis direction at a boundary of mutually adjacent ring surfaces in a ring-shaped phase structure formed in a region from a height of 75% to a height of 100% of an effective diameter maximum height of the optical surface on which the ring-shaped phase structure is formed and n is a refractive index of the objective lens at a design wavelength of λ_0 (nm), m_j represented by

$$m_j = INT(X) \tag{8B}$$

(wherein $X = \Delta_j \cdot (n-1)/(\lambda_0 \cdot 10^{-3})$ and INT(X) is an integer obtained by half adjust of X) is an integer not less than 2.

57. The optical information recording/reproducing apparatus of any one of claims 49 to 56, wherein in case of $W(\lambda_0, T_0)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_0 (nm) which is a design wavelength thereof is incident to the objective lens at an environmental temperature which is a first ambient temperature T_0 = 25 °C, $W(\lambda_1, T_0)$ is an RMS

value of residual aberration of the objective lens when light having a wavelength of λ_1 (nm) which is 5 nm longer than the wavelength of λ_0 is incident to the objective lens at the environmental temperature which is the first ambient temperature $T_0 = 25$ °C and $W(\lambda_2, T_1)$ is an RMS value of residual aberration of the objective lens when light having a wavelength of λ_2 (nm) is incident to the objective lens at the environmental temperature which is a second ambient temperature $T_1 = 55$ °C, $\Delta W1$ and $\Delta W2$ defined by

$$\Delta W1 = |W(\lambda_2, T_1) - W(\lambda_0, T_0)| \quad (9)$$

$$\Delta W2 = |W(\lambda_1, T_0) - W(\lambda_0, T_0)| \quad (10)$$

satisfy following formulas:

$$\Delta W1 < 0.035\ \lambda rms \quad (11)$$

$$\Delta W2 < 0.035\ \lambda rms \quad (12)$$

wherein

when $\lambda_0 < 600$ nm, $\lambda_2 = \lambda_0 + 1.5$ (nm) and

when $\lambda_0 \geq 600$ nm, $\lambda_2 = \lambda_0 + 6$ (nm).

58. The optical information recording/reproducing apparatus of claim 57, wherein the apparatus satisfies a following formula:

$$\sqrt{((\Delta W1)^2 + (\Delta W2)^2)} < 0.05\ \lambda rms \quad (13)$$

59. The optical information recording/reproducing apparatus of any one of claims 49 to 58, wherein the objective lens is an objective lens of a finite conjugate

type for converging a diverging light beam emitted from the light source on the information recording surface and satisfies a following formula:

$$1.1 > f > 0.2 \quad (13A)$$

60. The optical information recording/reproducing apparatus of claim 59, wherein the apparatus satisfies a following formula when m is an image formation magnification of the objective lens:

$$0.2 > |m| > 0.02 \quad (13B)$$

61. The optical information recording/reproducing apparatus of claim 59 or 60, wherein the objective lens and the light source are united by an actuator at least to be driven for tracking.

62. The optical information recording/reproducing apparatus of any one of claims 43 to 61, wherein the apparatus satisfies a following formula:

$$0.8 < d/f < 1.8 \quad (14)$$

where d (mm) is a lens thickness in an optical axis of the objective lens and f (mm) is the focal length.

63. The optical information recording/reproducing apparatus of any one of claims 43 to 62, wherein the design wavelength of λ_0 (nm) of the objective lens satisfies a

following formula:

$$500 \geq \lambda_0 \geq 350 \quad (15)$$

64. The optical information recording/reproducing apparatus of any one of claims 43 to 63, wherein the apparatus satisfies a following formula:

$$0.40 \leq (X1 - X2) \cdot (N - 1)/(NA \cdot f \cdot \sqrt{(1 + |m|)}) \leq 0.63 \quad (16)$$

where

X1: a distance (mm) in an optical axis direction between a plane that is perpendicular to an optical axis and tangent to a top of an optical surface on a light source side and an optical surface on the light source side in a most peripheral portion of an effective diameter (position of the NA on a surface on the light source side to which a marginal light beam is incident), wherein X1 is plus in a case of measuring X1 in a direction of the optical information recording medium with reference to the tangent plane, and minus in a case of measuring X1 in a direction of the light source,

X2: a distance (mm) in an optical axis direction between a plane that is perpendicular to an optical axis and tangent to a top of an optical surface on an optical information recording medium side and an optical surface on the optical information recording medium side in a most peripheral portion of an effective diameter (position of the NA on a

surface on the optical information recording medium side to which a marginal light beam is incident), wherein X2 is plus in a case of measuring X2 in a direction of the optical information recording medium with reference to the tangent plane and minus ina case of measuring X2 in a direction of the light source,

N: a refractive index of the objective lens at the design wavelength of λ_0,

f: the focal length (mm) of the objective lens, and

m: an image formation magnification of the objective lens.